1.0 INTRODUCTION

The Shasta River watershed was added to the California 303(d) list of impaired waterbodies for low dissolved oxygen in 1992 and for temperature in 1996. Staff of the North Coast Regional Water Quality Control Board's (Regional Water Board) Total Maximum Daily Load (TMDL) Development Unit are scheduled to complete the technical analyses for the Shasta River dissolved Oxygen and Temperature TMDLs by December 2004.

This draft Work Plan provides background information on TMDLs (**Section 1**) and presents Regional Water Board staff's planned approach for developing the Shasta River dissolved oxygen TMDL (**Section 2**). In addition, Regional Water Board staff's working hypotheses regarding dissolved oxygen conditions in the Shasta River watershed are discussed (**Sections 3 through 7**). Finally, a Monitoring Plan for the Shasta River dissolved oxygen TMDL is presented (**Section 8**).

1.1 TMDL Background

Section 303(d) of the federal Clean Water Act requires states to identify waterbodies that are impaired, to identify the particular pollutant(s) or stressor(s) that are causing impairment, and to develop a plan (the TMDL) to attain and maintain desired water quality conditions. An "impaired" waterbody is one that is not meeting water quality standards, which refers to the beneficial uses and water quality objectives of the waterbody, as stated in the North Coast Water Quality Control Plan (Basin Plan). A "beneficial use" refers to the designated uses of a waterbody, including municipal drinking water, agricultural supply, recreation, and habitat for cold water fish, to name a few. A "water quality objective" is a number or narrative description of the desired condition associated with a particular water quality parameter.

Regional Water Board staff are also in the process of developing TMDLs for the Klamath River for temperature, nutrients, and dissolved oxygen. The Oregon Department of Environmental Quality is developing TMDLs for the Upper Klamath River Subbasin for temperature, dissolved oxygen, pH, and Chlorophyll a. The Klamath River TMDLS (both California and Oregon components) are scheduled to be completed after the Shasta River TMDL is completed. One objective of the Shasta River TMDLs is to quantify how water quality conditions of the Shasta River affect the conditions of the Klamath River.

Components of a TMDL

There are four steps to developing a TMDL. The first step is developing a Technical TMDL. The second step is developing an Action Plan, which outlines a strategy and schedule to achieve pollutant load reductions. The third step involves getting approval of the TMDL and Action Plan by the Regional Water Board, the State Water Resources Control Board, and the U.S. EPA, and thus incorporating the TMDL into the Basin Plan. The fourth step is implementing the TMDL Action Plan. Regional Water Board staff are now working on the first step of the Shasta River TMDLs.

The Technical TMDL describes conditions in the watershed and includes a number of key elements.

- The **Problem Statement** characterizes water quality problem(s). It identifies water quality indicators and associated numeric targets, which are quantitative or narrative measures of desired waterbody-specific conditions. Targets can vary from place-to-place and from season-to-season.
- The **Source Analysis** quantifies the natural and human-related sources of the pollutant(s) or stressor(s) that are causing impairment.
- The **Linkage Analysis** draws links between land use conditions and water quality conditions.
- The **TMDL Loading Capacity** determines how much of the pollutant(s) or stressor(s) the waterbody can handle while still supporting the beneficial uses.
- Finally, the **Load Allocations** determine how much, if any, the identified sources need to be reduced in order to achieve the target conditions.

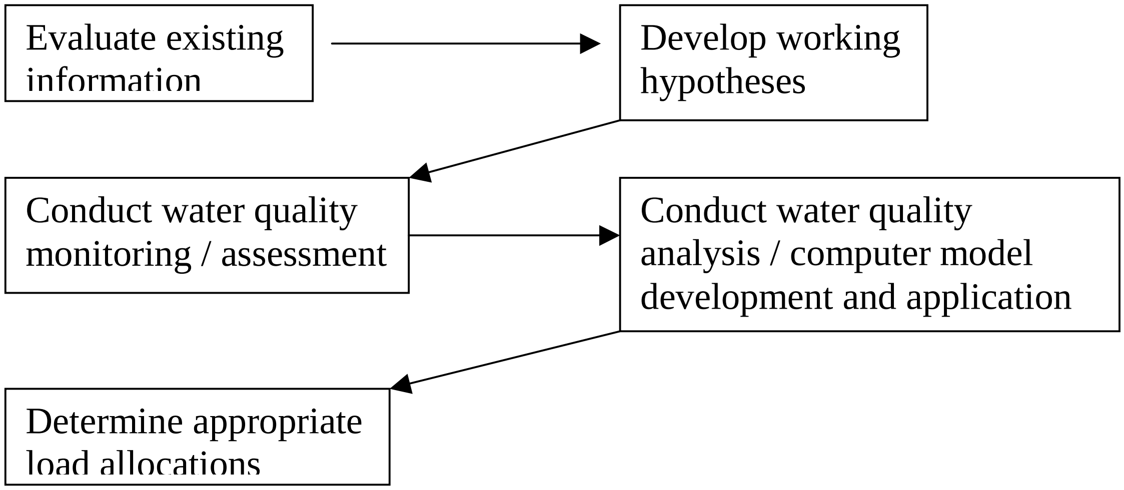
2.0 SCOPE, APPROACH, AND SCHEDULE

2.1 Scope of Shasta River Dissolved Oxygen TMDL

The listing of the Shasta River for dissolved oxygen on the 303(d) list applies to the entire Shasta River watershed. In other words, all surface waters that flow to the Shasta River and the mainstem itself are included in the listing. This does not necessarily mean, however, that the entire Shasta River watershed is impaired by low dissolved oxygen. A primary objective of the TMDL development process is to determine the areas within the Shasta River watershed that are, in fact, impaired by low dissolved oxygen. **In Sections 4 and 5** Regional Water Board staff assess dissolved oxygen impairment of the Shasta River watershed based on available data. The objective of the Monitoring Plan (Section 8) is to further define the area and timing of low dissolved oxygen in the Shasta River watershed. Ultimately, the TMDL Action Plan will apply only to those areas of the Shasta River watershed that are impaired by low dissolved oxygen and those areas that potentially contribute to the low dissolved oxygen conditions.

2.2 Conceptual Approach and Schedule for Developing Dissolved Oxygen TMDL

The conceptual approach to developing the Shasta River dissolved oxygen Technical TMDL is presented in the following flow chart.



The specific tasks for completing the key elements of the Technical TMDL are:

Problem Statement

- Review existing water quality, fisheries, and land use information
- Conduct literature review on various topics including dissolved oxygen requirements of salmonids, factors affecting dissolved oxygen levels in rivers, and water quality conditions associated with various land uses.

Source Analysis

- Conduct water quality monitoring in Shasta River watershed
- Conduct literature review on subjects including nutrient and organic material loading from various land uses.

Linkage Analysis

- Analyze and interpret water quality monitoring data
- Develop and apply computer model

Loading Capacity

- Application of computer model

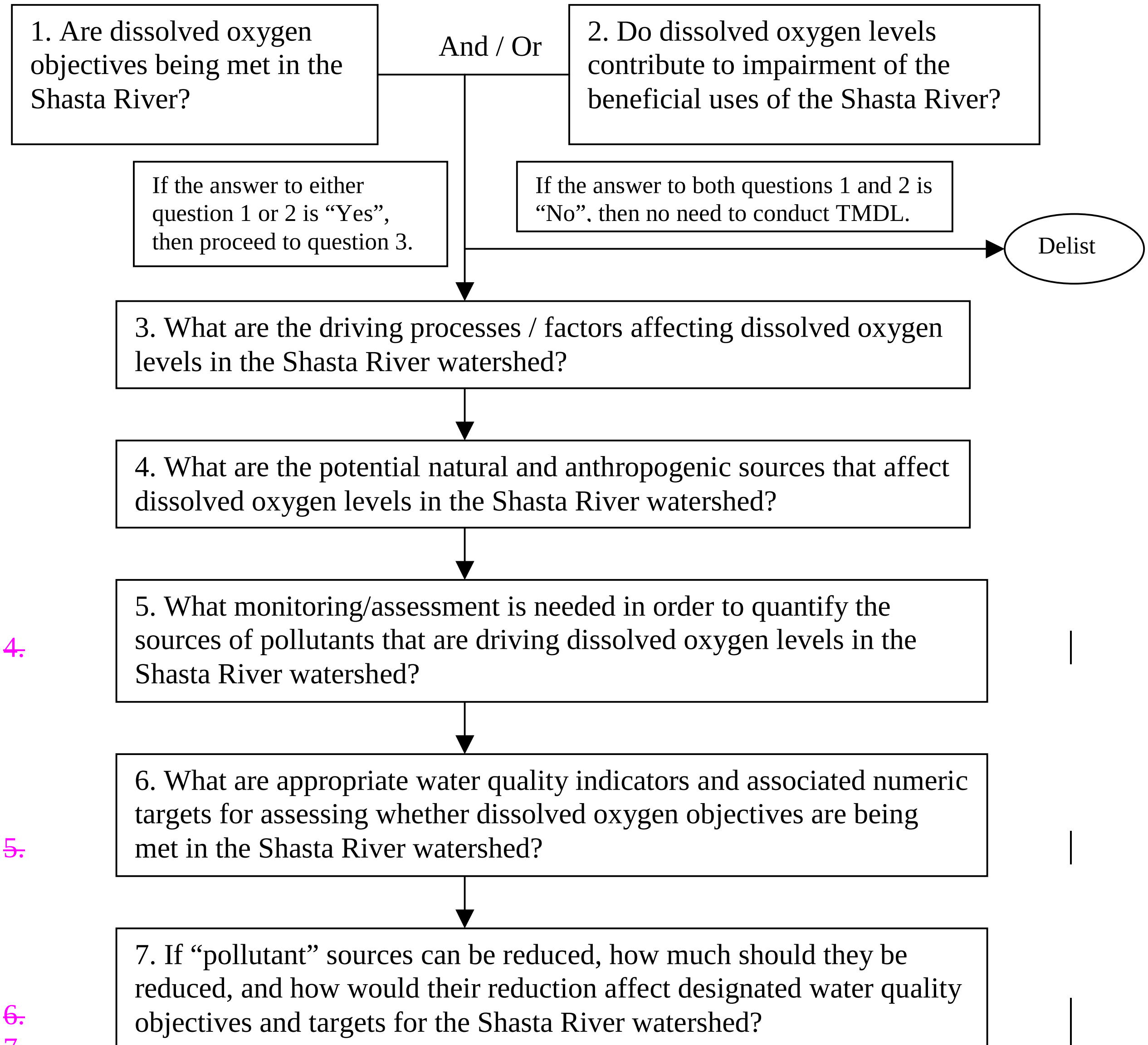
Load Allocation

- Application of computer model

The schedule for completing these tasks and the associated deliverables is presented in the attached Gantt chart at the end of the report.

3.0 KEY QUESTIONS FOR TMDL DEVELOPEMENT

In order to develop the dissolved oxygen Technical TMDL, Regional Water Board staff must answer the following questions:



~~4.~~
~~5.~~
~~6.~~
~~7.~~

This Work Plan addresses questions #1 – 5. Questions 6 and 7 will be addressed following implementation of the Monitoring Plan.

3.1 *Report Organization*

Sections 4 through 7 of this report are organized by questions #1 to 5, according to the following format:

Question → Hypothesis → Available information supporting hypothesis → Additional information needed to test hypothesis.

Regional Water Board staff have developed working hypotheses regarding Questions #1 to #5. Where available, information supporting the hypothesis is presented. Finally, additional information that is needed to test the hypothesis is identified. The Monitoring Plan (Section 8) summarizes the additional information needed to develop the dissolved oxygen TMDL.

3.2 *Comment on Data Quality*

Data is presented in this draft Work Plan from published and unpublished reports. The objective in presenting data in this report is to evaluate the spatial and temporal variability in water quality conditions in the Shasta River watershed, and to evaluate the causes of these water quality conditions. Regional Water Board staff have not attempted to assess the quality of all of this data. However, we have conducted a preliminary QA/QC review of the data collected by, or under contract with, the Regional Water Board. Data for which sample protocol and QA/QC criteria are not available are used by Regional Water Board staff in assessing the conditions of the watershed and in formulating the working hypotheses. Only data with a documented Quality Assurance Project Plan will be used in developing load allocations in the TMDL.

4.0 ARE DISSOLVED OXYGEN OBJECTIVES BEING MET?

Hypothesis #1:

> ***Dissolved oxygen levels vary spatially and temporally (seasonal and diurnal variation) in the Shasta River watershed. Dissolved oxygen levels fall below the minimum Basin Plan objective for several early morning hours per day between May and September in the reach of the Shasta River from approximately Montague Grenada Road to Yreka-Ager Road.***

The North Coast Water Quality Control Plan (Basin Plan) has the following dissolved oxygen objectives for the Shasta River watershed:

- Shasta River and other streams within Shasta Valley: minimum dissolved oxygen concentration of 7.0 mg/L, and a 50% lower limit of 9.0 mg/L. (This objective applies to the Shasta River and all tributaries that drain to the Shasta River.)
- Lake Shastina: minimum dissolved oxygen concentration of 6.0 mg/L, and a 50% lower limit of 9.0 mg/L.

The minimum dissolved oxygen objectives refer to the lowest dissolved oxygen level that shall be measured at any given time. The 50% lower limit represents the 50 percentile values of the monthly means for a calendar year. This means that 50% or more of the monthly means must be greater than or equal to the lower limit. The Basin Plan does not provide any guidance regarding the number of samples required to calculate the monthly means.

These Basin Plan dissolved oxygen objectives were developed by Regional Water Board staff and adopted by the Regional Water Board to protect the most sensitive beneficial use, the cold water fish. The dissolved oxygen objectives for the Shasta River were established based on dissolved oxygen requirements for salmonids.

One objective of a TMDL is to assess whether the water quality objectives are achievable for the given waterbody. For now, we assess the available Shasta River watershed dissolved oxygen data in light of the existing objectives.

Dissolved oxygen levels in surface waters are not constant, but are in fact changing throughout the day as oxygen is added to (by photosynthesis and reaeration) and removed from (by carbonaceous and nitrogenous deoxygenation, sediment oxygen demand, and respiration) the water. Typically, in productive waterbodies dissolved oxygen levels increase during the day (when oxygen is produced by aquatic plants through photosynthesis) and decrease at night (when oxygen-consuming processes such as respiration, carbonaceous and nitrogenous deoxygenation dominate).

Monitoring devices that measure dissolved oxygen levels hourly with a membrane electrode provide a good picture of how dissolved oxygen levels change throughout a 24-hour period. Alternatively, discrete dissolved oxygen measurements can be made with monitoring devices or via chemical titration.

Table 1 (located at the end of the report) provides a summary of the available dissolved oxygen data collected in the Shasta River watershed from 1953 through 2002. Table 1 identifies all of the locations at which dissolved oxygen levels have been measured, and presents the maximum, minimum, and median values recorded at each site for each data set. Table 1 also presents the percent of measurements below 7.0 mg/L for each data set. The monitoring locations are identified in **Figures 1** (located at the end of the report).

Figures 2 through 9 summarize dissolved oxygen measurements taken from 1986 to 2001 at eight locations in the Shasta River. The figures show the fraction of the measurements that are below a given dissolved oxygen concentration. These figures summarize dissolved oxygen measurements taken by Regional Water Board staff between 1988 and 1995, by the California Department of Fish and Game in 1994, and by the Shasta River CRMP in 2000 and 2001. Measurements by Regional Water Board and California Department of Fish and Game staff were taken between the hours 5 a.m. and 6 p.m.; the majority of the measurements were taken after sunrise. Measurements by the Shasta River CRMP were taken between 3 a.m. and 6 a.m., before sunrise.

Approximately 20, 70, 80, and 80 percent of the pre-dawn measurements taken in the Shasta River at Highway A12, Montague Grenada Road, Highway 3, and Yreka Ager Road (**Figures 4 to 7**), respectively, were below 7.0 mg/L. Approximately 15, 10, 25, and 15 percent of the measurements, predominantly taken after sunrise, in the Shasta River below Lake Shastina, at East Louie Road, Anderson Grade Road, and Highway 263 (**Figures 2, 3, 8, and 9**), respectively, were below 7.0 mg/L.

Figure 10 summarizes all dissolved oxygen measurements (at all monitoring locations) taken between 1988 and 1995 by Regional Water Board and California Department of Fish and Game staff, plotted as dissolved oxygen level versus the time of day at which the dissolved oxygen level was recorded. **Figure 10** demonstrates the pronounced fluctuation in dissolved oxygen levels corresponding to time of day, with the highest dissolved oxygen levels occurring during mid-afternoon when photosynthesis is most active, and the lowest dissolved oxygen levels occurring during pre-dawn hours when oxygen-consuming factors, such as respiration and sediment oxygen demand, dominate.

The Department of Water Resources (2002) measured dissolved oxygen levels approximately monthly at 22 locations in the Shasta River watershed, including measurements in most of the major tributaries to the Shasta River (**Table 1**). All of the measurements were taken after sunrise. With only a few exceptions, the majority of the measurements taken in tributary locations were above 7.0 mg/L. Forty one percent of the measurements taken in Lake Shastina were below the Basin Plan objective of 9.0 mg/L for Lake Shastina.

None of the available dissolved oxygen data sets are considered sufficient to compare to the 50% lower limit objectives.

Based on the available dissolved oxygen data, the following observations are made:

- The lowest dissolved oxygen concentrations (2 to 4 mg/L) in the Shasta River are experienced in the reach from approximately Montague Grenada Road to Yreka Ager Road. Regional Board staff consider this the reach of primary concern with regard to low dissolved oxygen (**Figure 11**).
- Low dissolved oxygen concentrations (5 to 7 mg/L) are also experienced in the reaches from East Louie Road to Montague Grenada Road and from Yreka Ager Road to Highway 263 in the Shasta River. Regional Board staff consider these reaches of secondary concern with regard to low dissolved oxygen (**Figure 11**).
- Dissolved oxygen concentrations less than 7 mg/L occur in these reaches between the months of May and September.
- Though all dissolved oxygen measurements in tributaries to the Shasta River have been taken after sunrise, dissolved oxygen measurements in tributaries predominantly exceed 7 mg/L, with few exceptions.
- Dissolved oxygen concentrations fall below 9 mg/L in Lake Shastina in May to October, with levels reaching <1 mg/L at depths exceeding 7 meters.
- Dissolved oxygen levels fluctuate significantly diurnally, consistent with photosynthetic activity. Dissolved oxygen concentrations less than 7 mg/L predominantly occur during early morning hours.

Additional Information Needed to Test Hypothesis #1:

To more completely characterize the spatial and temporal variability in dissolved oxygen levels in the Shasta River, and to Test Hypothesis #1, Regional Water Board staff will conduct dissolved oxygen measurements as outlined in **Task 1** "DO Measurements" of the Monitoring Plan (see **Section 8**).

5.0 DO DISSOLVED OXYGEN LEVELS CONTRIBUTE TO IMPAIRMENT?

Hypothesis #2:

> ***Dissolved oxygen concentrations reach stressful levels for all life stages of salmonids in the Shasta River watershed, and reach lethal levels in the Shasta River below Lake Shastina.***

A summary of dissolved oxygen requirements of salmonids is provided here, followed by a comparison of the available dissolved oxygen data for the Shasta River watershed to these requirements. The focus of this review is on salmonids, because this is the beneficial use most sensitive to low dissolved oxygen.

Impacts of Low Dissolved Oxygen on Salmonids

Adequate concentrations of dissolved oxygen are critical for the survival of salmonids. Fish have evolved very efficient physiological systems for obtaining and using oxygen in the water to oxygenate the blood and meet their metabolic demands (WDOE 2000). However, reduced levels of dissolved oxygen can impact growth and development of different life stages of salmon, including eggs, alevins, and fry, as well as the swimming, feeding and reproductive ability of juveniles and adults. Such impacts can affect fitness and survival by altering embryo incubation periods, decreasing the size of fry, increasing the likelihood of predation, and decreasing feeding activity. Under extreme conditions, low dissolved oxygen concentrations can be lethal to salmonids.

Salmonid Avoidance of Low Dissolved Oxygen

Salmonids have been shown to actively avoid dissolved oxygen concentrations above the levels that would cause acute lethality, and that chronically low dissolved oxygen levels will determine the presence and distribution of salmonids in fresh waters (Davis 1975). Field and laboratory studies have found that avoidance reactions in salmonids consistently occur at concentrations of 5.0 mg/L and lower (WDOE 2000).

Acute Mortality of Salmonids Due to Low Dissolved Oxygen

Mortality of salmonids has generally been found at concentrations below 3 mg/L (US EPA 1986), with mortality becoming consistently high at oxygen levels at or below 2.5

mg/L (WDOE 2000). Mortality is not expected when minimum oxygen concentrations are at 3.5-4 mg/L or higher, even in warm (20°C) waters (WDOE 2000).

Life Stage Requirements of Dissolved Oxygen

Theoretically, a critical oxygen level for each species exists (Colt et al. 1979); however, limited data is available. Therefore, the following information applies to salmonids in general, with specific species referenced as appropriate.

<u>Adult Migration</u>

The upstream migration by adult salmonids is typically a stressful endeavor. Sustained swimming over long distances requires high expenditures of energy and therefore requires adequate levels of dissolved oxygen. Davis et al. (1963) reported that maximum sustainable swimming speeds of juvenile and adult coho salmon were reduced when dissolved oxygen dropped below saturation at temperatures between 50-68 °F. Further, swimming performance dropped sharply when dissolved oxygen was decreased to 6.5-7.0 mg/L at all temperatures studied. Migrating adults exhibited an avoidance response when dissolved oxygen was below 4.5 mg/L, and resumed migration when dissolved oxygen was at 5.0 mg/L (Hallock et al. 1970). McMahon (1983) recommends dissolved oxygen levels >6.3 mg/L for successful upstream migration of anadromous salmonids.

EPA (1986) presents the following table for salmonid life stages other than embryonic and larval:

Level of Effect	Water Column DO (mg/L)
No Production Impairment	8
Slight Production Impairment	6
Moderate Production Impairment	5
Severe Production Impairment	4
Limit to Avoid Acute Mortality	3

<u>Embryo Incubation and Fry Emergence</u>

Embryonic and larval stages are especially susceptible to low dissolved oxygen levels as their ability to extract oxygen is not fully developed and their relative immobility prevents them from migrating to more favorable conditions. The dissolved oxygen requirements for successful incubation of embryos and emergence of fry is tied to intragravel dissolved oxygen levels. Intragravel dissolved oxygen is typically a function of many chemical, physical, and hydrological variables, including: the dissolved oxygen of the overlying stream water, temperature, substrate size and porosity, biochemical oxygen demand of the intragravel water and substrate, the gradient and velocity of the stream, channel configuration, and depth of water.

Embryos can survive when dissolved oxygen is below saturation (and above a critical level), but development typically deviates from normal (WDOE 2000). Embryos were found to be smaller than normal and hatching either delayed or premature when dissolved oxygen was below saturation throughout development (Doudoroff and Warren 1965).

Silver et al. (1963) found newly hatched steelhead and chinook alevins were smaller and weaker when embryos were incubated at low or intermediate dissolved oxygen levels as compared to embryos incubated at high dissolved oxygen levels. Reduced dissolved oxygen levels lengthened the incubation period of coho embryos and also produced smaller alevins than normal (Shumway el al. 1964). Field studies have shown that survival of steelhead (Cobel 1961) and coho embryos (Phillips and Campbell 1961) is correlated to intragravel dissolved oxygen. Significant reductions in survival and size at emergence, and significant delays in time to hatch are likely to occur if intergravel dissolved oxygen concentrations fall below 6-6.5 mg/L (WDOE 2000). Phillips and Campbell (1961) concluded that intragravel dissolved oxygen must average 8 mg/L for embryos and alevins to survive well. Embryo survival drops significantly at concentrations ≤ 6.5 mg/L and concentrations < 3.0 mg/L are lethal (Coble 1961; Shumway et al. 1964; Davis 1975). For successful reproduction of anadromous species, Bjorn and Reiser (1991) recommend dissolved oxygen near saturation and temporary reductions should not drop below 5.0 mg/L. McMahon (1983) recommends dissolved oxygen levels be ≥ 8.0 mg/L for high survival and emergence of fry.

EPA (1986) presents the following table for salmonid embryo and larval stages:

Level of Effect	Water Column DO (mg/L)	Intragravel DO (mg/L)
No Production Impairment	11	8
Slight Production Impairment	9	6
Moderate Production Impairment	8	5
Severe Production Impairment	7	4
Limit to Avoid Acute Mortality	6	3

The EPA assumes a 3 mg/L loss in dissolved oxygen from the surface waters to the intragravel. In waterbodies with highly sedimented gravels this loss can be significantly higher (WDOE 2000).

<u>Freshwater Rearing</u>

Salmonids are strong active swimmers requiring highly oxygenated waters (Spence 1996) and this is true during the rearing period when the fish are feeding, growing, and avoiding predation. Davis (1975) reported no impairment to rearing salmonids if the dissolved oxygen averaged 8.0 mg/L, with deprivation beginning at 6.0 mg/L. Davis (1963) and Dahlberg et al. (1968) found that the maximum swimming speed of coho and chinook decreased when dissolved oxygen dropped below saturation (8-9 mg/L at 68°F), and below 6.0 mg/L swimming speed was significantly reduced. Growth rate and food conversion efficiency of coho fry is optimum at dissolved oxygen above 5.0 mg/L (McMahon 1983) with growth and food conversion decreasing rapidly when dissolved oxygen drops to below 4.5 mg/L (Herrmann et al. 1962; Brett and Blackburn 1981).

Evaluation of Shasta River Salmonids with Respect to Dissolved Oxygen Requirements

Populations of Shasta River fall chinook, steelhead and coho spawners appear to be in decline (CDFG, 2002; NMFS, 1995; NMFS, 1996; NMFS, 1997). Shasta River fish kills (spawners and juveniles) have been attributed, at least in part, to low dissolved oxygen levels in the Shasta River.

Based on the available data, dissolved oxygen levels reach lethal levels (< 3 mg/L) for limited periods of time in the Shasta River below Lake Shastina (**Figure 12**), at Highway 3 (**Figure 13**), Yreka Ager Road (**Figure 14**), and at Highway 263 (**Figure 15**). Further, a comparison of the threshold levels discussed above to the available Shasta River dissolved oxygen data shows that dissolved oxygen concentrations reach stressful levels for all salmonid life stages in much of the Shasta River (**Figures 2 through 9**). The dissolved oxygen data presented in **Table 1** also indicate that dissolved oxygen conditions in a number of the tributaries to the Shasta River reach stressful levels.

Based on this information, low dissolved oxygen levels do contribute to the impairment of cold water fish in the Shasta River.

Additional Information Needed to Test Hypothesis #2:

As more dissolved oxygen data is collected in the Shasta River watershed, and as a more complete assessment of salmonid distribution is assembled, Regional Water Board staff will develop maps identifying the distribution of various life stages of salmonids present in the Shasta River watershed at different times of year, along with a corresponding summary of reported dissolved oxygen levels.

6.0 WHAT ARE THE DRIVING PROCESSES/FACTORS AFFECTING DISSOLVED OXYGEN LEVELS?

Dissolved oxygen levels in surface waters are controlled by a number of interacting processes, including photosynthesis, respiration, carbonaceous deoxygenation, nitrogenous deoxygenation, nitrification, reaeration, and sediment oxygen demand (**Figure 16)**. ***Photosynthesis*** is the process by which solar energy is stored as chemical energy in organic molecules, and in doing so oxygen is liberated and carbon dioxide is consumed. The organic matter then serves as an energy source for bacteria and animals in the reverse process of ***respiration*** and decomposition, whereby oxygen is consumed. ***Carbonaceous deoxygenation*** is the technical term for decomposition, involving the consumption of oxygen by bacteria during the break down of organic material. ***Nitrogenous deoxygenation*** involves the conversion of organic nitrogen to ammonia by bacteria, a process that consumes oxygen. Nitrification is the process by which ammonia is oxidized to nitrite and nitrate. Sediment ***oxygen demand*** refers to the consumption of oxygen by sediment and organisms (such as bacteria and invertebrates) through both the decomposition of organic matter and respiration by plants, bacteria, and invertebrates.

The solubility of oxygen is a function of water temperature, salinity, an atmospheric pressure; decreasing with rising temperature and salinity, and increasing with rising atmospheric pressure. At sea level freshwater has a saturation dissolved oxygen concentration of about 14.6 mg/L at 0°C (32°F) and 8.2 mg/L at 25°C (77°F).

The amount of bio-available nutrients in a waterbody affects the extent of aquatic vegetation growth. Major nutrients include carbon, nitrogen, phosphorus, and silicon. Nitrogen and phosphorus are generally the main nutrients controlling plant and algal growth. Generally, increased nitrogen and phosphorus levels in a waterbody promote growth of aquatic vegetation. Subsequently, the extent of aquatic vegetation growth in freshwaters affects the amount of oxygen produced and consumed through photosynthesis and respiration.

Further, the amount of organic material present in a waterbody affects the potential for dissolved oxygen to be consumed as the material is decomposed by bacteria (expressed as carbonaceous deoxygenation and sediment oxygen demand). There are two sources of organic material in a waterbody: 1) aquatic vegetation growing in the stream itself (called autochthonous sources); and 2) external sources such as leaf/grass litter, soil erosion, and animal wastes (called allochthonous sources).

These two factors, the amount of nutrients and organic material in a waterbody, are interrelated to some degree, as abundant growths of aquatic vegetation stimulated by elevated nutrient levels can lead to oxygen consumption when the aquatic vegetation is decomposed.

Hypothesis #3:

> ***A factor causing low dissolved oxygen levels in the Shasta River is oxygen consumption associated with microbial decomposition of organic material, measured as biochemical oxygen demand and sediment oxygen demand.***

There are a number of lines of evidence that support Hypothesis #3. Available dissolved oxygen, biochemical oxygen demand (BOD), and total organic carbon (TOC) data from the Shasta River watershed is reviewed here. To our knowledge, no sediment oxygen demand (SOD) data has been collected in the watershed.

The river reach from Montague Grenada Road to Yreka-Ager Road, which experiences the lowest dissolved oxygen levels in the watershed, is a depositional reach, characterized by a buildup of organic material. The low dissolved oxygen levels experienced in this reach may be attributed, at least in part, to oxygen consumption resulting from breakdown of organic material.

Table 2 presents the available biological oxygen demand (BOD) data for the Shasta River. BOD is a measure of the amount of oxygen consumed by bacteria during the decomposition of organic material. Though the quantity of data is quite limited, the data indicates that Shasta River BOD levels are higher than levels found in “natural pristine” waterbodies. Reports document that a typical BOD level for a "natural pristine" surface waterbody is approximately 1.0 mg/L (Welch, 1992).

Available total organic carbon (TOC) data is presented in **Table 3**. TOC is a measure of the amount of organic carbon present in a water sample. The data indicates the presence of organic material, likely suspended algae and organic matter carried by irrigation return flows. For purposes of comparison, the average dissolved organic carbon level of temperate and arid or semiarid zones is 3 mg/L (USGS, 2002). The available TOC data from the Shasta River watershed are higher than this average.

Assessment Needed to Test Hypothesis #3:

To test Hypothesis #3 Regional Water Board staff will measure BOD and SOD at 3 to 6 locations in the Shasta River in August or September 2003, as detailed in Task 2 "Biological and Sediment Oxygen Demand Study" of the Monitoring Plan (see **Section 8**). Biochemical oxygen demand is a measure of the amount of oxygen required by bacteria while stabilizing decomposable organic matter present in a water column under aerobic conditions. Sediment oxygen demand is a measure of the amount of oxygen consumed in the sediments by microbial decomposition of organic matter and respiration of benthic organisms. SOD levels of sandy bottom sediments and estuarine muds range from 0.2 – 1.0 and 1 – 2 g $O_2/m^2 \bullet$ day, respectively (Thomann and Mueller, 1987).

The objective of the BOD/SOD study is to quantify the amount of oxygen consumed in the water column and in the sediments at select locations in the Shasta River. SOD levels are higher in stream reaches that have a build up of organic material on the bottom of the channel. Therefore, candidate SOD monitoring locations (identified in Task 2 of Section 8) have been selected to represent reaches with organic material-rich conditions.

Sediment oxygen demand will be monitored in-situ using an enclosed chamber embedded in the substrate of a channel, and measuring dissolved oxygen levels over time, consistent with USGS protocol (USGS, 1995; Wood, 2001). Sediment will also be collected near the chambers and analyzed for percent water, sand, and organic material. Sediment samples will also be collected at additional locations in the watershed for analysis of percent water, sand, and organic material. Regional Water Board staff will use these sediment analysis results to extrapolate SOD levels to different areas in the watershed. At the time of the SOD measurements water samples will be collected and analyzed for BOD at each of the SOD monitoring locations. Additional BOD measurements will be made as outlined in Tasks 4, 5, and 7 of the Monitoring Plan (**Section 8**).

The BOD/SOD study will be done once in the summer (August or September), because SOD typically does not vary significantly in the summer months (USGS, 1995; Wood, 2001). The study will be done in the summer, because this is the period of concern with regard to low DO in the Shasta.

Hypothesis #4:

Natural background concentrations of nutrients exceed state and national objectives, and are at levels that promote growths of aquatic vegetation.

A summary of regional and national nutrient objectives is presented here.

The Basin Plan does not have a numeric objective for nutrients. The Basin Plan does, however, have a narrative objective for biostimulatory substances, as follows:

> Waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses.

In 2001 the EPA developed recommended nutrient criteria for 13 aggregate ecoregions (**Figure 17**) for rivers and streams of the United States (US EPA, 2002). EPA's recommended ecoregional nutrient criteria represent conditions of surface waters that have minimal impacts caused by human activities. The criteria are suggested baselines. California is in the process of refining these ecoregional criteria. The total phosphorus and total nitrogen criteria for ecoregion II, which includes the Shasta River, are 0.01 and 0.12 mg/L, respectively.

The EPA's ***Quality Criteria for Water*** (US EPA, 1986) has a "desired goal" of 0.1 mg/L for total phosphates as phosphorus for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments. Further, the "desired goal" states that total phosphates as phosphorus should not exceed 0.05 mg/L in any stream at the point where it enters any lake or reservoir, nor 0.025 mg/L within the lake or reservoir.

Tables 4 through 8 present summaries of available total phosphorus, ortho-phosphorus, ammonia nitrogen, nitrate plus nitrite nitrogen, and organic nitrogen plus ammonia nitrogen data from the Shasta River watershed. A review of the available nutrient data indicates that nutrient levels in the Shasta River watershed regularly exceed the EPA criteria and desired goals, and are often at levels known to cause nuisance growths of aquatic plants.

An important objective of the Shasta River dissolved oxygen TMDL is to quantify the various sources of nutrients, including the natural background levels of nutrients in the Shasta River watershed. In other words, we must determine the amount of nutrients that are naturally present in the water, and the amount that is present as a result of human-related sources. One way to assess this is to compare nutrient levels to a "reference" site or "reference" condition. The reference site/condition should be one that is not affected by human-related sources of nutrients. Among the sites monitored in the Shasta Valley to date, none represent an ideal reference site.

Assessment Needed to Test Hypothesis #4:

To test Hypothesis #4, we will assess the natural background levels of nutrients in the Shasta River watershed at locations believed to represent reference conditions. The objective is to determine the range in nutrient levels from sites that are minimally affected by human-related activities in the Shasta Valley, and at sites characterized by varying geology. The monitoring locations are outlined in Task 3 “Characterization of Natural Background Levels of Nutrients” of the Monitoring Plan (**Section 8**).

The Shasta Valley is distinguished by a giant debris avalanche of the pleistocene age from ancestral Mount Shasta Volcano. Exposed debris avalanche deposits underlie the western two-thirds of the Shasta Valley. The avalanche deposits are overlain on the east by basaltic lava flows. Granitic deposits overlay volcanic soils in some western tributaries. The Shasta River flows across the avalanche deposits and younger basaltic lava flows. Reference sites have been selected to reflect these varying geologic conditions.

Regional Water Board staff will monitor for nutrients once per month from May through October 2003. Monitoring is limited to these months because this is the period during which low dissolved oxygen levels are experienced in the watershed. Further, though the available data indicates nutrient inputs occur year round, Regional Water Board staff believe nutrient inputs during higher flow periods do not exceed the assimilative capacity of the waterbody, and are generally diluted and flushed through the system.

7.0 WHAT ARE THE POTENTIAL NATURAL AND ANTHROPOGENIC SOURCES THAT ARE DRIVING DISSOLVED OXYGEN LEVELS?

As discussed in the previous section, the principle “pollutants” that control dissolved oxygen levels include nutrients and carbonaceous organic materials. Potential sources of nutrients and carbonaceous organic materials are discussed separately below.

7.1 Nutrient Sources

There are a number of potential sources of nutrients in a surface waterbody, including: natural weathering of rocks and soil; runoff from urban, agricultural, and forest lands; discharge from wastewater treatment facilities; subsurface inflow to surface waters from wastewater disposal ponds/fields; phosphorus-based pesticide application; release of ortho-phosphorus and ammonia from sediment under anaerobic conditions; inflow from groundwater; atmospheric deposition; fixing of atmospheric nitrogen to ammonia by blue green algae; and direct deposition of livestock waste into surface waters.

Hypothesis #5:

> ***The sources of nitrogen and phosphorus in the Shasta River watershed that contribute to nutrient loading to the Shasta River include:***
>
> ***a. Natural weathering of rocks and soil;***
>
> ***~~d.~~b. Irrigation return flows from agricultural lands;***

~~c.~~c. Subsurface inflow to surface waters from wastewater disposal ponds/fields;
d. Release of ortho-phosphorous and ammonia from sediments in Lake Shastina under anaerobic conditions;
e. Fixing of atmospheric nitrogen to ammonia by blue green algae in Lake Shastina;
f. Atmospheric deposition of nitrogen; and
g. Direct deposition of lifestock waste into surface waters.

Information Supporting Hypothesis #5:

a. <u>Natural weathering of rocks and soil</u>: Rock and soil are a primary source of nitrogen and phosphorus, particularly phosphate (**Figures 18 and 19**). The content of phosphate in rock/soil, and the associated contribution to phosphorus loading to surface waters, varies by rock/soil type.

The Shasta River watershed has a complex geology, including volcanic soils, as described in the previous section. Volcanic soils typically have high levels of phosphate compared to other soil types.

b. <u>Irrigation return flows from agricultural lands</u>: No known monitoring of irrigation return flows has been conducted in the Shasta Valley. However, irrigation return flows are common in the watershed, and water quality monitoring by the Regional Water Board's Surface Water Ambient Monitoring Program (SWAMP) suggests irrigation return flows influence the water quality of the Shasta River. **Figure 20** presents total dissolved solids (TDS) data collected throughout northern California by SWAMP. TDS consist of both organic and inorganic molecules and ions present in solution. **Figure 20** shows that levels of TDS in the Shasta River at Highway 263 are the highest recorded in northern California by the Regional Water Board. While the geology of the Shasta Valley clearly plays a role in these levels, Regional Water Board staff hypothesize that the high TDS levels are attributed in part to irrigation return flows, a land use more prevalent in the Shasta Valley compared to other northern California watersheds.

Water quality monitoring of the Shasta River at locations downstream of return flows also show higher levels of nutrients compared to upstream locations during summer months when irrigation return flows occur. For example, monitoring data from the Shasta River at Montague Grenada Road and at Highway 3 (stations MGR and HWY3) generally show higher levels of total phosphorus during the irrigation season compared with upstream locations, such as Shasta River below Lake Shastina (station DWIN).

The Central Valley Regional Water Quality Control Board is developing a water quality monitoring program of agricultural lands, including irrigation return flows. Data from this program is not currently available, but Regional Water Board staff will assess the data with respect to the Shasta River data, when available.

c. <u>Subsurface inflow to surface waters from wastewater disposal ponds/fields</u>: None of the wastewater treatment facilities in the Shasta Valley discharge to surface waters.

However, available water quality data indicate there may be subsurface inflow to surface waters from wastewater treatment facilities. Monitoring data in Yreka Creek upstream and downstream of the City of Yreka wastewater disposal site shows a large increase in total phosphorus levels downstream of the disposal site (see stations YCABY and YCDS in **Table 4**). In addition, total phosphorus levels in Oregon Slough downstream of the Montague wastewater disposal ponds (see station OSNRSR) may suggest influence of the disposal ponds. Finally, monitoring of Boles Creek downstream of the City of Weed disposal ponds (station BCNRWD) may also suggest influence of the disposal ponds.

d. <u>Release of phosphorous and ammonia from sediments in Lake Shastina under anaerobic conditions</u>: The release of phosphorus from sediment under anaerobic conditions is a complex biochemical process. In short, as dissolved oxygen levels near the sediment-water interface approach zero, iron present in the soil changes form, and phosphorus that was bound to the initial form of iron is solubilized and released into the water. This process can act as a significant source of soluble phosphorus in some waterbodies (Welch, 1992).

Proteins in organic matter are converted to ammonia by the action of heterotrophic bacteria under aerobic and anaerobic conditions. The ammonia released by bacterial action may be used by aquatic plants directly to produce plant protein (Welch, 1992; Sawyer et al. 1994)

If orthophosphate (bound to iron) and organic nitrogen is present in sediments, and if dissolved oxygen levels approach zero, ortho-phosphorus and ammonia can be released. The relative importance of this source is dependent on the quantity of phosphorus and organic nitrogen in the sediments and the duration for which dissolved oxygen levels approach zero at the sediment-water interface. Based on the total phosphorus and nitrogen levels in the water in Lake Shastina, we suspect the Lake Shastina sediments are a sink for these nutrients. Dissolved oxygen levels approached zero near the bottom of Lake Shastina approach zero from June through September 2001 (CDWR, 2002).

The following table summarizes dissolved oxygen, ortho-phosphorus, and ammonia concentrations measured near the sediment-water interface in Lake Shastina in the summer of 2001 (CDWR, 2000). The data indicates that orpho-phosphorus and ammonia are released under anaerobic conditions in Lake Shastina.

Date	**Depth (meters)**	**Dissolved Oxygen (mg/L)**	**Ortho-Phosphorus (mg/L)**	**Ammonia (mg/L)**
May 2001	14	4.8	0.02	0.18
June 2001	14	0.2	0.15	1.1
July 2001	11	0.1	0.02	0.12
August 2001	7	No Measurement	0.03	0.27
Sept 2001	7	0.3	0.05	0.26
Oct 2001	7	3.8	0.01	No measurement

e. Fixing of atmospheric nitrogen to ammonia by blue green algae in Lake Shastina: An evaluation of the ratio of nitrogen to phosphorus concentrations in water indicates the "limiting nutrient". The limiting nutrient is defined as the nutrient that limits plant growth when it is not available in sufficient quantities. The ratio of nitrogen to phosphorus in plant material is typically 7.2:1. Generally, when the nitrogen to phosphorus ratio in water is less than 7.2, nitrogen is limiting. Ratios above 7.2 indicate that phosphorus is limiting. An evaluation of the most recent, complete data set for the Shasta River watershed including Lake Shastina (CDWR, 2002) indicates that, with a few exceptions, the nitrogen to phosphorus ratio in the watershed is less than 7.2.

Blue green algae have the ability to fix atmospheric nitrogen under nitrogen limited conditions. Presence of blue green algae has been reported in Lake Shastina (USGS, 1974). Nitrogen fixation by blue green algae can account for nearly 50% of the annual nitrogen inputs in enriched waterbodies (Welch, 1992). Based on this information, it is possible that blue green algae present in Lake Shastina utilize the ability to fix atmospheric nitrogen, and serve as a source of nitrogen to the system.

f. Atmospheric deposition of nitrogen: Nitrogen originating from multiple sources can be deposited from the atmosphere in several forms. Ammonia, volatilized to the atmosphere from fertilizers and animal wastes, can be dissolved in rain and return to aquatic environments. Oxides of nitrogen can also be released into the atmosphere by lightning and combustion. Again, these nitrogen oxides can become dissolved in rain, and be deposited back to aquatic systems. The highest reported loads of atmospheric nitrogen deposition are 30-40 kg N/ha/year (University of California Water Resources Center, 2002). These conditions were found in southern California, an area with significant vehicle and industry emissions contributions.

g. Direct deposition of livestock waste into surface waters:Studies show that livestock wastes containorganic forms of nutrients. Based on anecdotal information, including Regional Water Board staff observations, livestock have direct access to some surface waters of the Shasta River watershed, resulting in direct deposition of waste to these waterways.

Assessment Needed to Test Hypothesis #5:

In order to test Hypothesis #5, the loads from sources A through F must be quantified. A pollutant load is a mass per time, and is calculated by multiplying the pollutant concentration by flow. Regional Water Board staff will quantify the loads from sources A through f in two ways. First, we will conduct water quality and flow monitoring as detailed below. In addition, pollutant loading rates for different land use categories (e.g. urban, pasture, irrigated pasture, etc.) reported in the literature will be used to corroborate the loads calculated from Shasta River watershed monitoring data.

a. Natural weathering of rocks and soil: To quantify the amount of phosphorus loading attributed to the natural weathering of rocks and soils Regional Water Board staff will conduct nutrient analysis of native soil samples. The exact sample locations have not been determined, but will be representative of native and undisturbed soil and rock from various geologic areas in the watershed (using SCS soil maps). Subsequently, an estimate of soluble phosphorus leaching rates, as well as erosion rates contributing total phosphorus sorbed to soil particles, will be made based on values presented in the literature. A load estimate of this source will be computed based on the estimated leaching and erosion rates and on stormwater runoff records (or estimates of runoff rates based on recorded rainfall rates, according to standard hydrologic principles).

In addition, we will assess natural background levels of nutrients, as outlined in **Task 3** “Characterization of Natural Background Levels of Nutrients” of the Monitoring Plan (**Section 8**).

b. Irrigation return flows from agricultural lands: See **Task 4** “Irrigation Return Flows Monitoring” of the Monitoring Plan (**Section 8**).

c. Subsurface inflow to surface waters from wastewater disposal ponds/fields: See **Task 5** “Wastewater Disposal Source Identification” of the Monitoring Plan (**Section 8**).

d. Release of ortho-phosphorous and ammonia from sediment under anaerobic conditions: The release of ortho-phosphorus and ammonia from sediment under anaerobic conditions can be determined based on given physical and chemical conditions. Phosphorus release rates from sediment under anaerobic conditions are well documented in the literature. In addition to the monitoring outlined in **Task 6** “Lake Shastina Profile Study”, Regional Water Board staff will apply reported phosphorus and ammonia release rates to those areas of Lake Shastina that become anaerobic, where applicable.

e. Fixing of atmospheric nitrogen to ammonia by blue green algae: See **Task 6** “Lake Shastina Profile Study” of the Monitoring Plan (**Section 8**). In addition to monitoring for chlorophyll a, we will collect algae samples for species identification. Based on information on algal species present, Regional Water Board staff will apply nitrogen fixation rates by blue green algae reported in the literature.

f. Atmospheric deposition of nitrogen: Regional Water Board staff will apply appropriate rates of atmospheric deposition of nitrogen reported in the literature.

g. Direct deposition of livestock waste to surface waters: This input will be quantified through the source analysis, applying nutrient loads associated with livestock waste reported in the literature.

7.2 Sources of Organic Material

Potential sources of oxygen demanding carbonaceous organic material in a surface waterbody include: vegetation growing in the waterbody; vegetation that falls or is washed into the waterbody; discharge from wastewater treatment facilities; subsurface inflow to surface waters from wastewater disposal ponds/fields; organic rich sediments washed into surface waters from urban areas, agricultural, or forest lands during storms; irrigation return flows; and atmospheric deposition.

Hypothesis #6:

> ***The sources of organic material in the Shasta River watershed that contribute to organic material loading to the Shasta River include:***
> ***a. Vegetation growing in the waterbody***
> ***b. Irrigation return flows***
> ***c. Subsurface inflow to surface waters from wastewater disposal ponds/fields***
> ***d. Direct deposition of livestock waste to surface waters***

There is limited available water quality data that characterizes the input of organic materials in the Shasta River watershed.

a. Vegetation growing in the waterbody: The supporting information for Hypothesis #1 also applies here.

b. Irrigation return flows: As mentioned previously, no known monitoring of irrigation return flows has been conducted in the Shasta Valley. Further, there is limited BOD data. In the absence of this data, Regional Water Board staff review available total dissolved solids (TDS) data from the watershed (**Table 9**) as a surrogate of oxygen demanding materials, to assess the potential influence of irrigation return flows on the water quality of the Shasta River. TDS levels are highest in the reach of the Shasta River downstream of areas dominated by agricultural use (see stations HYW3 to HWY5 in **Table 9**). This may suggest that irrigation return flows are a source of organic material.

c. Subsurface inflow to surface waters from wastewater disposal ponds/fields: The available data of oxygen demanding organic materials downstream of the Shasta Valley wastewater disposal sites is also quite limited. Again, Regional Water Board staff evaluates TDS levels as a surrogate of oxygen demanding materials. The TDS levels in Yreka Creek and Oregon Slough downstream of the Yreka and Montague wastewater disposal sites (see stations YCDS and OSNRSR in **Table 9**) are among the highest recorded in the Shasta Valley.

d. Direct deposition of livestock waste into surface waters:Studies show that livestock wastes contain organic materials which exert an oxygen demand. Based on anecdotal information, including Regional Water Board staff observations, livestock have direct access to some surface waters of the Shasta River watershed, resulting in direct deposition of waste to these waterways.

Assessment Needed to Test Hypothesis #6:

a. Vegetation growing in the waterbody: The BOD/SOD study (**Task 2** of the Monitoring Plan) will serve to test Hypothesis #6a. In addition, Regional Water Board staff will use literature values of photosynthesis, respiration, and mortality rates to model the affect of aquatic vegetation in the Shasta River on dissolved oxygen levels.

b. Irrigation return flows: See **Task 4** "Irrigation Return Flows Monitoring" of the Monitoring Plan.

c. Subsurface inflow to surface waters from wastewater disposal ponds/fields: See **Task 5** "Wastewater Disposal Source Identification" of the Monitoring Plan.

d. Direct deposition of livestock waste to surface waters: This input will be quantified through the source analysis, applying organic material loads associated with livestock waste reported in the literature.

Hypothesis #7:

Dissolved oxygen concentrations in spring flows are low, and contribute to low dissolved oxygen levels in downstream reaches.

Regional Water Board staff know of no reported dissolved oxygen data from spring flows in the Shasta River watershed.

Assessment Needed to Test Hypothesis #7:

See **Tasks 1, 3, and 7** of the Monitoring Plan.

8.0 MONITORING PLAN

This Monitoring Plan outlines the monitoring/assessment that Regional Water Board staff plan to complete to develop the Shasta River dissolved oxygen TMDL. Additional rationale for the specific monitoring tasks is presented in the previous sections.

8.1 Quality Assurance Project Plan

Regional Water Board staff have developed a draft ***Klamath Basin TMDLs Quality Assurance Project Plan*** (QAPP). The QAPP outlines data quality objectives, sampling procedures, equipment calibration and reporting, quality control procedures, and documentation. Water quality monitoring conducted by Regional Water Board staff will be done according to this Plan.

8.2 Tasks

Task 1: DO Measurements

Objectives:

- To test Working Hypothesis #1 & 7.
- To characterize the temporal and spatial variation of dissolved oxygen levels in the Shasta River watershed.

What	Where	When	How	Why
Hourly DO measurement	Shasta @ Edgewood Road	Mid-April through September 2003	YSI 6920 per protocol described in USGS, 2000 and Radtke et.al. 1998. Monitoring to be conducted by USGS.	To characterize DO variability of Shasta River above Shastina. To extend existing DO data set at this site.
Same as above	Shasta @ Montague-Grenada Rd	Same as above	Same as above	To extend existing data set at this site.
Same as above	Shasta @ Hwy 3	Same as above	Same as above	To extend existing data set at this site.
Same as above	Shasta @ Hwy 263	Same as above	Same as above	To extend existing data set at this site.
Same as above	Shasta @ Riverside Drive	2-3 day period during week of June 16 and week of August 18 to	YSI 6600 per protocol described in USGS, 2000 and Radtke et.al. 1998. Monitoring to be	To extend existing data set at this site.

		coincide with parcel tracking study	conducted by RWQCB.	
Same as above	Shasta below confluence with Big Springs Cr	Same as above	Same as above. Temp and DO measurements will be used to determine well-mixed site that represents Big Springs contribution.	To characterize the influence of Big Springs Creek on DO in Shasta. No DO data has been collected at this location.
Same as above	Shasta @ Grenada Pumps	Same as above	Same as above.	To characterize DO conditions between Big Springs and Montague Grenada Rd
Same as above	Shasta @ A-12	Same as above	Same as above.	Same as above
Same as above	Little Shasta River near confluence with Shasta, flow permitting	Same as above	Same as above	To extend DO data set at this site.
Same as above	Oregon Slough near confluence with Shasta	Same as above	Same as above	
Discrete DO measurements (grab samples).	Parks Creek near confluence with Shasta	Spot measurements during 2-3 day period during week of June 16 and week of August 18	YSI 600XL. Monitoring to be conducted by RWQCB.	To characterize DO conditions at this site
Same as above.	Big Springs Creek	Same as above.	Same as above	Same as above.
Same as above	Yreka Creek near confluence with Shasta	Same as above	Same as above	Same as above

Task 2: Biochemical and Sediment Oxygen Demand Study

Objectives:

- To test Working Hypothesis #3.
- To quantify biochemical and sediment oxygen demand in select locations of the Shasta River.

SOD will be measured at 3 to 6 sites in the Shasta River. Measurements will be made within four reaches of the Shasta River: East Louie Road to A12; A12 to Montague Grenada Road; Montague Grenada Road to Highway 3; and Highway 3 to Highway 263. Candidate sites are identified below. Alternatively, measurements will be taken at 3 to 4 locations within the depositional reach near Montague-Grenada Road in order to provide a detailed characterization of SOD variability within a specific reach.

What	Where	When	How	Why
Measurement of BOD and SOD	Shasta @ E. Louie Rd in depositional area	3-hr test in August or September	SOD chambers per protocol presented in USGS 1995.	E. Louie Rd is the most upstream area that has pockets of fine organic material deposits.
Same as above.	Shasta @ Grenada Pumps	Same as above	Same as above	
Same as above.	Shasta @ A-12	Same as above.	Same as above.	
Same as above.	Shasta @ Montague-Grenada Road	Same as above.	Same as above.	
Same as above.	Shasta @ Hwy 3	Same as above.	Same as above.	
Same as above	Shasta @ Hwy 263	Same as above.	Same as above.	
Same as above	Shasta @ Webb property	Same as above	Same as above	Stream gradient downstream of this site generally restricts deposition, and we assume SOD is negligible below this site.

Task 3: Characterization of Natural Background Levels of Nutrients

Objectives:

- To test Working Hypothesis #4.
- To characterize the spatial and temporal variability of nutrient levels at locations within the Shasta River watershed that have minimal effect of human-related impacts and represent the geologic variability of the basin.

What	Where	When	How	Why
Ammonia (diss); Ammonia plus organic N (diss); Nitrate plus Nitrite (diss); ortho-phosphate (diss); total phosphorus; Chl a, pH, specific conductance, DO, temperature	Upper Beaughton Creek between source spring and Weed city limits	1X/mo. May - Oct	Depth integrated grab sample	This site was chosen to represent ”unimpacted” surface water draining from Mount Shasta.
Same as above	Parks Creek above West Fork	Same as above	Same as above.	This site was chosen to represent “unimpacted” surface water draining from the Eddy Mountains
Same as above	Yreka Creek @ Oberlin Road	Same as above	Same as above.	This site was chosen: 1) to extend the existing data set for this site, 2) to include Greenhorn flows, and 3) to represent relatively “unimpacted” surface water of the Yreka Cr drainage.
Same as above.	Little Shasta River @ Ball Mtn Rd, 8 miles u/s of Harry Cash Rd	Same as above	Same as above	This site was chosen to represent “unimpacted” surface water draining Little Shasta Drainage/

				Goose Nest upstream of exposed debris flow
Same as above	Big Springs Creek	Same as above	Same as above	We are assuming flows originating from springs represents "unimpacted", background conditions. This site was chosen b/c it represents a significant portion of the flow in the Shasta at it's confluence.
Same as above	Kettle or Nigger Springs or "other" that drains to Parks	Same as above	Same as above.	Same as above. One spring that drains to Parks will be selected to represent springs potentially draining from Eddy Mtns.
Same as above	Cold, Jim, Tunnel, Bassy, Evan, or Soda Spring	Same as above	Same as above	Same as above. Two of the listed springs will be sampled to represent springs draining Little Shasta watershed and Goose Nest area.

Task 4: Irrigation Return Flows Monitoring

Objectives:

- To test Working Hypotheses #5B & 6B.
- To characterize the water quality of representative irrigation return flows in the Shasta Valley.

Note: Irrigation return flows will be sampled at 2 to 4 locations. Candidate locations are identified below. Where possible, samples will be collected from the irrigation source water in addition to the return flows.

What	Where	When	How	Why
Ammonia (diss); Ammonia plus organic N (diss); Nitrate plus Nitrite (diss); ortho-phosphate (diss); total phosphorus; TOC; BOD, TDS, pH, specific conductance, DO, temperature	Shasta @ Montague-Grenada Rd	1X/mon May – Oct Note the exact timing at each site will be dependent on irrigation practices.	Well mixed grab samples	Return flow at this location includes flows from more that one landowner. We will attempt to capture runoff from the largest area possible. Also, will attempt to sample first and second flows thru the pump-back system.
Same as above	Oregon Slough	Same as above	Same as above	
Same as above	Shasta d/s of A-12	Same as above	Same as above	
Same as above	Shasta near Grenada Pumps	Same as above	Same as above	Sample pre- and post-tailwater capture pond.
Same as above	Shasta near A-12	Same as above	Same as above	Irrigation water at this location is likely to pick up elements from alkali ground.
Same as above		Same as above	Same as above	Attempt to sample pre- and post- infiltration pond flows.
Same as above	Water from Little Shasta River, eventually reaching Cloak Lake	Same as above	Same as above	Though these flows don’t drain to the river, they likely represent typical return flow quality.

Task 5: Wastewater Disposal Source Identification

Objectives:

- To test Working Hypotheses #5C & 6C.
- To assess whether the wastewater disposal ponds/fields in the Shasta Valley effect surface water quality.

Note: Sample locations just upstream and downstream of the disposal ponds/fields have been selected.

What	Where	When	How	Why
Ammonia (diss); Ammonia plus organic N (diss); Nitrate plus Nitrite (diss); ortho-phosphate (diss); total phosphorus; TOC; BOD, TDS, pH, specific conductance, DO, temperature	Yreka Creek @ Hwy 3 bridge at the north end of town and @ Nursery bridge	Every other month, May to December	Depth integrated grab samples	Evaluate influence of Yreka disposal fields on water quality of Yreka Cr.
Same as above	Oregon Slough @ Ager Road and @ Western Railroad bridge	Same as above	Same as above	Evaluate influence of Montague secondary treatment ponds on water quality of Oregon Slough.
Same as above	Boles Creek – locations TBD	Same as above	Same as above	Evaluate influence of Weed disposal ponds on water quality of Boles Cr.
Same as above	Shasta River @ Riverside Drive and @ Hidden Valley Ranch	Same as above	Same as above	Evaluate influence of Shastina disposal ponds on water quality of Shasta River.
Same as above	TBD in vicinity of Grenada disposal area.	Same as above	Same as above	Need to do site recon to evaluate possibility of surface water effect.

Task 6: Lake Shastina Profile Study

Objectives:

- To test Working Hypothesis #5D & 5E.
- To evaluate nutrient speciation at varying depths in Lake Shastina.
- To assess the release of ortho-phosphorus and ammonia from lake bottom sediments under anoxic conditions.

What	Where	When	How	Why
Ammonia (diss); Ammonia plus organic N (diss); Nitrate plus Nitrite (diss); ortho-phosphate (diss); total phosphorus; Chl a; pH; specific conductance; DO; temperature; redux; algal species	@ northern and southern end of Shastina at approximately 0, 4, 8, and 12 meter depths; exact depths dependent on evaluation of lake stratification.	Early September; sample one day at approx. 8 am and 2 pm	Grab samples with Kemmer sampler	

Task 7: Parcel Tracking Study

Objectives:

- To Test Working Hypothesis #7.
- To understand fate and transport of water quality parameters in the Shasta River below Lake Shastina.
- To provide water quality data for use in model calibration/validation.

What	Where	When	How	Why
Ammonia (diss); Ammonia plus organic N (diss); Nitrate plus Nitrite (diss); ortho-phosphate (diss); total phosphorus; Chl a; TOC; BOD, TDS, pH, specific conductance, DO, temperature	Shasta River d/s of Big Springs Creek	One time during week of June 16 and week of August 18	Depth integrated sample	This site was chosen to represent conditions in Shasta River below Shastina, but including influence of Big Springs Creek
Same as above	Shasta @ Montague-Grenada Road	Same as above	Same as above	To extend existing data set for this site.
Same as above	Shasta @ Hwy 3	Same as above	Same as above	To extend existing data set for this site.
Same as above	Shasta @ Hwy 263	Same as above	Same as above	To extend existing data set for this site.
Same as above	Shasta @ A-12	Same as above	Same as above	Sampling will be done at this site if sufficient funds are available
Same as above	Shasta @ Grenada Pumps	Same as above	Same as above	Same as above

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